A SYSTEM AND METHOD FOR PROVIDING CONTEXT TO OPERATOR OVERLOADING

Field of the Invention

The illustrative embodiment of the present invention relates generally to operator overloading in an object oriented language-based development environment, and more specifically to the providing of context through the use of parse tree information during operator overloading.

Background

Objects provide a way for programmers to extend the basic data types in a programming language to provide higher-level data types specific to their application. Objects are also used to package specific tools or capabilities, such as graphical packages or mathematical packages, so that they can be used effectively in larger applications. Objects typically consist of properties or members, which hold data from the basic data types, and may also contain other objects, and methods, functions designed to work specifically on a particular object. Often, Object Oriented Languages (OOLs) will provide a way of overloading the basic operations of the language, including addition, subtraction, multiplication, division, assignment, subscripting, and field reference. Typically, this is done by providing special methods that get invoked when these operators are used on members of the class. For example, if *x* and *y* are members of a class *C*, then if the user writes

```
x + y
```

the class system might invoke the overloaded

```
Plus( x, y )
```

in response to the '+' operator in order to compute the "sum" of *x* and *y*. The Plus function will typically perform some other operations extending, or in place of, the addition operation." (there would be no reason to overload the '+' operator if all that was going to happen was an ordinary addition of the two variables).

Unfortunately, there are many cases when the traditional operator overloading method does not meet user needs. For example, people writing code for an embedded

processor frequently must simulate the behavior of computers with unusual instructions and word lengths. Also, speed of execution is frequently critical, so simulating complicated instructions when simple instructions will do is not an acceptable alternative. Finally, programmers may desire more control over the order of operations than is provided by the base language.

Additionally, in conventional object-oriented languages, operator overloading is specified by defining methods in the class that correspond to the operators that are being overloaded. This specification suffers from the deficiencies that the objects that participate in an expression are only processed in pairs, and that there is no opportunity to discover the context in which a given expression appears.
As an example, consider

```
y = x + 1
```

If x is a 16-bit variable, but y is only 8 bits wide, then the addition can be done in 8 bits rather than 16. However, the conventional overloading method does not allow information from the left side of the assignment operator to be seen on the right side—the only thing that the overloaded Plus operator sees is x and 1. Put another way, the context in which the operation is occurring is not visible during the mathematical operation.

An additional problem with conventional methods of overloading operators is that the conventional methods have difficulty with complicated instructions. An example is given by

```
x + y*z
```

Some embedded processors have special instructions that will multiply two numbers and add the result into a third (a multiply and accumulate or MAC instruction). It is very difficult in the usual operator overloading paradigms that operate on two operands to recognize and properly simulate MAC instructions.

<u>Brief Summary</u>

The illustrative embodiment of the present invention provides a method of operator overloading that enables a class designer to view both the structure of the operands of the operation being overloaded, and also the context in which the operator

is being used. The present invention utilizes a parse tree created by a language processor. The use of the parse tree, which is represented as a class, allows the context information to be made available to the class designer. Objects of the parse tree class include methods designed to identify the operator at a root and to retrieve left and right trees. An assignment function is defined which uses two parse tree objects as arguments and performs an indicated mathematical operation based upon the context revealed by the parse tree objects. The assignment function may exist in more than one class and be overloaded. The overloading of the assignment function enables the context within which the mathematical operation is occurring to become visible and be acted upon.

In one embodiment in a program development environment, a method provides a parse tree data structure written in a base language. An assignment function is defined which takes more than one parse tree object as arguments. The assignment function is then called to determine the value of an assignment within the base language or an extension to the base language.

In another embodiment, in a program development environment, a method provides a parse tree data structure written in a base language. An assignment function is defined which takes more than one parse tree object as arguments. The assignment function is then called to determine the value of an assignment within the base language or an extension to the base language. Code is then generated for an embedded processor using the parse tree data structure.

In a different embodiment, in a program development environment, a method provides a parse tree data structure written in a base language. An assignment function is defined which takes more than one parse tree object as arguments. The assignment function is then called to determine the value of an assignment within the base language or an extension to the base language. The parse tree data structure is then used in software emulation.

In an embodiment, a system includes a program development environment having a base language. The system also includes a parse tree data structure which includes methods able to retrieve values for base language objects. An assignment

function is also included in the system, the assignment function taking multiple parse tree structures as arguments. The assignment function is called to determine the value of at least one assignment within the base language or an extension to the base language.

In another embodiment, in an object-oriented program development environment having a base language, a method provides a parse tree data structure which is used as the basis for at least one parse tree object. The parse tree object includes methods able to retrieve values for base language objects. An assignment function is defined which takes more than one parse tree structure as arguments in more than one class. The assignment function is then called to determine the value of an assignment within the base language or an extension to the base language. The assignment function is used to overload a mathematical operator based on the context of the parse tree objects.

Brief Description of the Drawings

Figure 1 depicts an environment suitable for practicing the illustrative embodiment of the present invention;

Figure 2 is a flowchart of the sequence of steps followed by the illustrative embodiment of the present invention to create parse tree objects;

Figure 3 is a flowchart of the sequence of steps followed by the illustrative embodiment of the present invention to define and use an assignment function; and

Figure 4 is a flowchart of the sequence of steps followed by the illustrative embodiment of the present invention to determine whether streamlined in-place operations can be performed.

Detailed Description

The illustrative embodiment of the present invention provides a class designer the opportunity to overload operators in an object oriented language-based design environment based upon the structure of the operands of the operation being overloaded as well as the context in which the operator is being used. The structure of the operands and the operator context is used by the designer to decide what

properties the class should have, and what methods should be provided, and also to implement and test the chosen methods. The present invention enables designers to build classes with a top-down view of operator overloading thus enabling the fashioning of behaviors that would be difficult or impossible to obtain with conventional object-oriented systems.

Figure 1 depicts an environment suitable for practicing the illustrative embodiment of the present invention. The present invention is practiced on an electronic device 2 holding a program development environment 4. The program development environment 4 may be an object-oriented language based environment, or alternatively, may be a non-object-oriented language based environment. For purposes of illustration, the discussion below will focus on an object-oriented implementation. The electronic device 2 may be a desktop, workstation, mainframe, server, PDA, laptop or some other type of electronic device with a processor and holding an object oriented language-based development environment. The program development environment 4 utilizes a Language Processor 6, which, as discussed further below, turns programs written in an object-oriented language such as C++ , MATLAB or other object oriented language into a functioning application. The Language Processor 6 is used to build a parse tree 8 data structure from the source code 10 for a computer program written in an object-oriented language. The various methods of building a parse tree with a Language Processor are common knowledge to those skilled in the art, and are discussed at length in textbooks such as *Aho, Sethi & Ullman,* Compilers: Principles, Techniques, and Tools, Addison Wesley, 1986.

A *Tree* class represents this Parse Tree, whose exact form depends on the Base Language upon which this invention is applied. The illustrative embodiment of the present invention includes the built-in class, called *Tree*, and associated behavior in the Language Processor 6 that treats this *Tree* class specially. Class *Tree* has methods called *kind,* that tells what kind of an operator is at the root of the tree, and *left* and *right* methods that deliver the left and right *Trees*, if present. When a *Tree* is simply a constant, methods are available to get the value of the constant. When a *Tree* is a simple variable, methods are available to get the value of the variable and the associated information about it (for example, its class and size).

Those skilled in the art will recognize that when the program development environment 4 is not object-oriented, parse tree data structures may be built without the use of a class using traditional computer programming data structures familiar to those with a sequential programming background. It will be further appreciated throughout the discussion herein that the examples and illustrations made with reference to an object-oriented programming environment are also applicable to non-object oriented programming environments without departing from the scope of the present invention.

The illustrative embodiment of the present invention may be used during class design by the designer. To use the present invention on a class (referred to herein as class *C*), the designer must write a function, *Assign,* based on class *C* (those skilled in the art will recognize that the name of the function is immaterial to the operation of the present invention). The function *Assign* takes two *Tree* objects as arguments and is used by the Language Processor 6. The Language Processor 6 uses the Assign function as follows. Whenever there is an assignment, such as

```
X = Y
```

Then the Language Processor 6 calls the *Assign* function

```
Assign( t1, t2 )
```

where *t1* is the *Tree* object corresponding to *X* and *t2* is the *Tree* object corresponding to *Y*. This function evaluates the value of *t2* and assigns the value to the tree object represented by *t1*. When there is an indexing expression on the left side of an assignment, such as

```
a(i) = Y
```

then the *Assign* function is called with *t1* being the *Tree* representing the expression a(i) and *t2* representing the expression *Y*. The *Tree* class also contains special nodes that can be used in contexts where there is no explicit assignment--for example, parameters in a function call or use as a subscript. The exact set of nodes defined for these purposes varies depending upon the details of the Base Language.

For most of the classes built-in to the Base (object-oriented) Language, the value is well-defined and there is no need to specify the *Assign* function explicitly. The *Tree* class has a built-in method, called *Val* that follows the usual rules for obtaining the value of Base Language objects. Other methods of the Tree class may

include left ( ), and right ( ) (which return left and right Trees respectively), and getClass( ), and getSize( ) which are used to get the class and size of a variable or tree.

Figure 2 depicts the sequence of steps followed by the illustrative embodiment of the present invention to utilize the parse tree 8 created by the Language Processor 6 (step 20). The sequence begins with the source code 10 in the object oriented language-based development environment being accessed by the Language Processor 6. The Language Processor then examines the source code 10 (step 22). The Language Processor 6 then creates the parse tree 8 (step 24). As previously noted, the parse tree data structure 8 is represented as a class from which different tree objects are later instantiated (step 26). Each tree object includes the attributes and methods specified in the class definition and discussed above.

When there are several classes all using the invention, it is necessary to define several functions called *Assign*. This process is called *overloading*, and is known to those skilled in the art. The invention works slightly differently in this case depending on the characteristics of the Base Language. When operators are overloaded in the Base Language, then every expression has a known class associated with it. In this case, the choice of the appropriate *Assign* function is determined by the class of the expression represented by the *Tree* that is its second argument. (In some Base Languages, the order of the two arguments to the *Assign* function may be interchanged to make this fit more naturally into the rules for overloading).

Figure 3 depicts the sequence of steps followed by the illustrative embodiment of the present invention to define and overload an assignment function (e.g.: the *Assign* function discussed above) in order to determine operator context. The sequence begins when the class designer defines an assignment function (step 30). The class designer may then optionally overload the evaluation function by defining the assignment function in different classes (step 32). The class designer then writes the assignment function that uses the parse tree objects as arguments (step 34). The overloaded assignment function then allows the operation to be processed based upon the particular class being assigned to (step 36). This invention thus specifically addresses those cases where some of the behavior desired by the Designer is the overloading of arithmetic and other types of operators.

Some of the uses of the present invention may be illustrated by reference to the following examples.

Example 1: **In-Place Operations.**

The objects in class *C* may take up a large amount of memory. For example, the objects may be large matrices containing thousands of elements. Certain kinds of arithmetic on these objects may be done "in place". For example, an expression such as

```
A = A + 1
```

may be computed by adding 1 to each element of A. In conventional operator overloading, however, it is not possible to recognize this important optimization. The above expression would conventionally be evaluated by

1. Creating a temporary object--*T*.
2. Computing the value of $A + 1$ into *T*.
3. Freeing the old object *A*.
4. Renaming *T* to *A*.

The process of object allocation and freeing adds significant overhead to this operation, and doubles the amount of memory needed to carry out this operation. Using the present invention, it is possible to recognize in-place operations. Then a call

```
Assign( t1, t2 )
```

to the *Assign* function would operate as follows:

1. The *kind* of the top node of *t2* would be examined to see if it supported in-place operations.
2. If so, the *left* operand of *t2* would be examined to see whether it matched *t1*.
3. If so, the in-place operation would be done.
4. Otherwise, the more traditional operation would be done.

Depending on the base language, there may be other conditions that need to be met before the in-place operation could be safely used, but such tests are easily coded. It should be noted that in many cases steps 1 and 2 could be done by the Language Processor by looking at the trees only once, when the class description was processed. When this is possible, the in-place operation can become a "compile-time optimization". In effect, the invention serves to extend the compiler optimizations,

leading to faster, smaller run-time code. In other cases, the tests may be performed at run time, but may still represent a significant optimization opportunity.

Figure 4 depicts the sequence of steps followed by the illustrative embodiment of the present invention to determine whether expedited in-place operations may be performed. The sequence begins with the *kind* of the top node of *t2* being examined (step 50) to see if it supports in-place operations (step 51). If the top node of *t2* does support in-place operations (step 51), the left operand of *t2* is examined (step 52) to see if it matches *t1* (step 53). If the left operand of *t2* does match *t1*, the expedited in-place operation described above is performed (step 54). Otherwise, the traditional form of in-place operation is performed (step 56).

Example 2: **Methods that Look Like Properties.**

A classic example in object-oriented language textbooks is an object, *Pt*, that represents a point. It has two properties, *x* and *y*, that represent the coordinates of the point. It also has two methods, *r* and *theta*, which represent the polar coordinates of the point. So if *p* is an object of class *Pt*,

```
p.x
p.y
p.r()
p.theta()
```

may be used to obtain the values of *x*, *y*, *r*, and *theta* for *p*. This appears asymmetric to a user viewing the code, so often the properties are given hidden names, and methods are supplied to access *x* and *y* as well as *r* and *theta*. To set the x, y, r and theta values, four additional methods, *setx, sety, etc.* are needed to allow the setting of each of these parameters in turn. This is a cumbersome and inefficient way to process simple points.

Using the methodology of the present invention, it is now possible to allow a user to set each of these values using the natural "dot" notation, but still have all of the advantages of hiding the underlying implementation. ~~A *Value*~~ An *Assign* function is defined that looks at the left side tree to see if the root node is DOT. If so, it looks at the property name and calls the appropriate set method for *x*, *y*, *r*, or *theta*. Similarly, on the right-hand side, *Assign* looks for a dot and calls the appropriate method to

obtain the property. This type of use of the *Assign* function raises an issue. The value being assigned is not a *Pt* object, but rather a coordinate or angle. The way to manage this is to make the coordinates and angles members of a class derived from the built-in class that holds the coordinate values (for example, a defined class *Coord* derived from the built-in class *double*). Then the *Assign* function is actually defined for values of class *Coord* rather than *Pt*.

Example 3: **Detailed Version of Previous Example.**

The definition of the *Assign* function for *Coord*s, as described in the previous example may be represented as follows using a language similar to C++ as the Base Language:

```
void Coord:Assign( Tree t1, Tree t2 )
{
     Coord temp;
     switch( kind( t2 ) )
     {
     case DOT:
          if( right(t2).isname( "x" ) )
          {
               temp = Val(left(t2)).get_x();
               break;
          }
          similarly with y, r, and theta
     default:
          temp = Val(t2);
          break;
     }
     /* at this point, temp is defined */
     switch( kind( t1 ) )
     {
     case DOT:
          if( right(t1).isname( "x" ) )
          {
               Val(left(t1)).set_x( temp );
               break;
          }
          similarly with y, r, and theta
     default:
          Assign( t2, temp );
     }
}
```

Much of the above logic may be carried out at "compile time", thus leading to efficient output code.

Example 4: **Constraining Evaluation Order**

Another application of the invention allows class designers to enforce a particular order of evaluation on overloaded operators. For example, in a statement like

```
X = A + B + C;
```

most languages do not make any guarantees about the order of evaluation of the right hand side--whether *A* is first added to *B*, and then the result is added to *C*, or whether *B* and *C* are added together and then *A* is added to that sum. The class designer can enforce an order of evaluation of the operands of an overloaded operator by using the *Assign* function. By first evaluating the *left* operand of an operator and then the *right*, it is possible to enforce left-to-right evaluation--by evaluating the *right* operand first, it is possible to force right-to-left evaluation.

The illustrative embodiment of the present invention may also be used to write code for an embedded processor. Because the illustrative embodiment of the present invention enables the context in which operations are occurring, the present invention is particularly useful when simulating the behavior of computers with unusual instructions and word lengths and in processing MAC type instructions. As a result of the ability to generate code for embedded processors and to optimize the code based on the context of operations, the illustrative embodiment of the present invention has application to DSP, Microcontrollers, general purpose processors, FPGAs(Field Programmable Gate Arrays) and processor emulation.

Since certain changes may be made without departing from the scope of the present invention, it is intended that all matter contained in the above description or shown in the accompanying drawings be interpreted as illustrative and not in a literal sense. Practitioners of the art will realize that the system configurations depicted and described herein are examples of multiple possible system configurations that fall within the scope of the current invention. Likewise, the sequences of steps utilized in the illustrative flowcharts are examples and not the exclusive sequence of steps possible within the scope of the present invention.